(12) UK Patent Application (19) GB (11) 2 170 358 A

(43) Application published 30 Jul 1986

(21) Application No 8501636

(22) Date of filing 23 Jan 1985

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(51) INT CL⁴
H01P 5/12

(52) Domestic classification (Edition H)
H1W 7 CX
U1S 2093 H1W

(56) Documents cited
None

(58) Field of search
H1W
Selected US specifications from IPC sub-class H01P

(54) Microwave power divider

(57) A microwave power divider comprises a Wilkinson power splitter having, from its input A, a microstrip line 4 which divides at 6 into two lines 7 and 8 each ¼ wavelength long, having their outputs B_1 and C_1 connected by a resistor 9. A quadrature delay in the form of a ½ wavelength long transmission line 10 is connected between B_1 and one output B of the divider. An incremental phase compensator in the form of a band pass filter is connected between C_1 and the other output C of the divider, and comprises a ¼ wavelength long transmission line 11 connected between C_1 and C and two ¼ wavelength long stubs 12 and 13 connected to C_1 and C and short-circuited to earth.

At the centre frequency, line 10 delays the signal by 180°, line 11 by 90° and stubs 12 and 13 have no effect, so that a 90° phase difference occurs between B and C outputs. As the frequency varies, the same phase increment occurs in the filter (by suitable selection of its characteristics) as in the line 10, to maintain the outputs in quadrature.
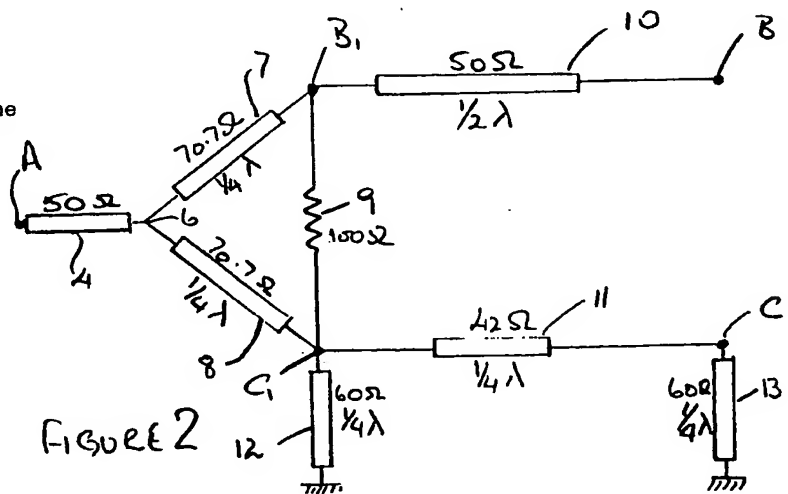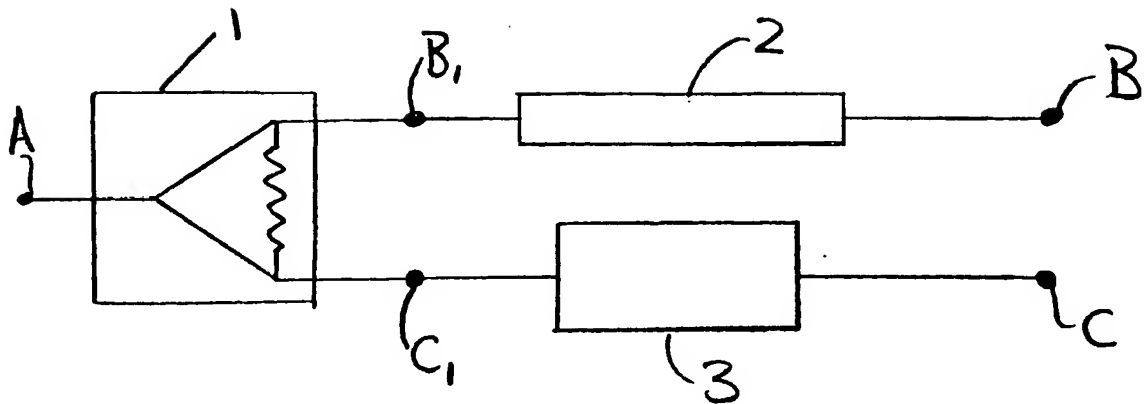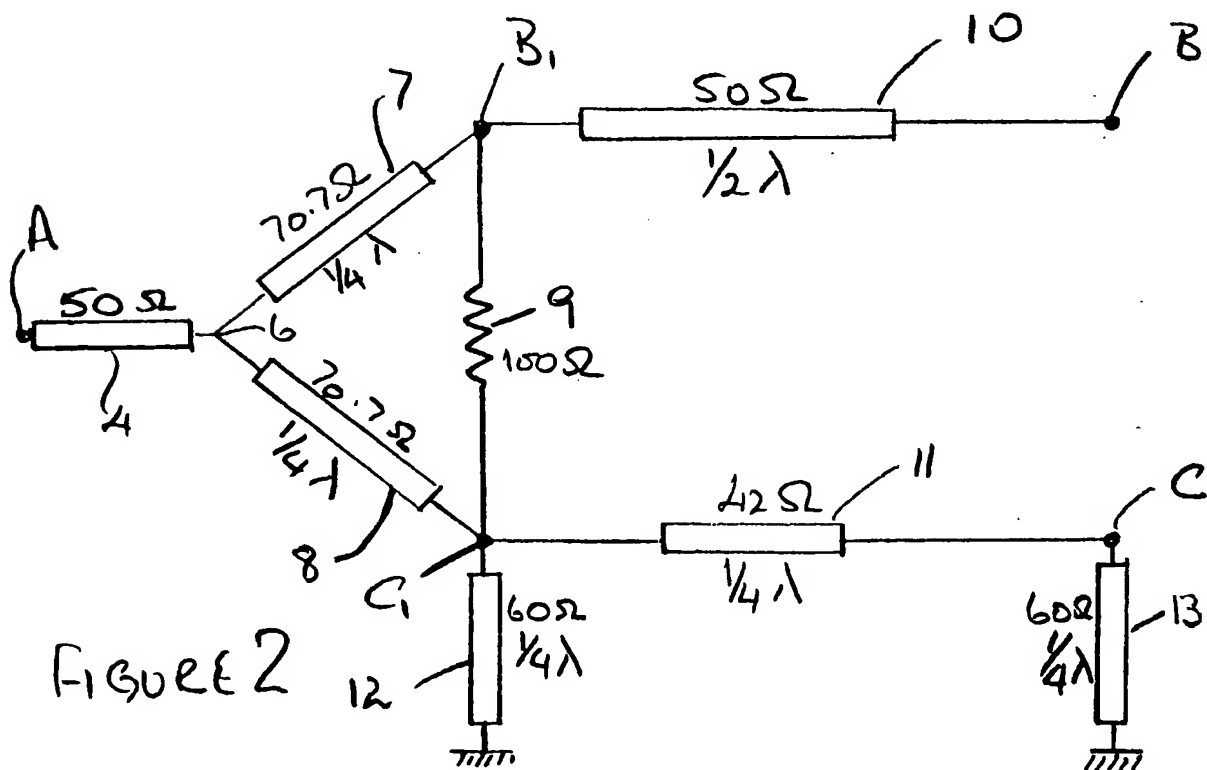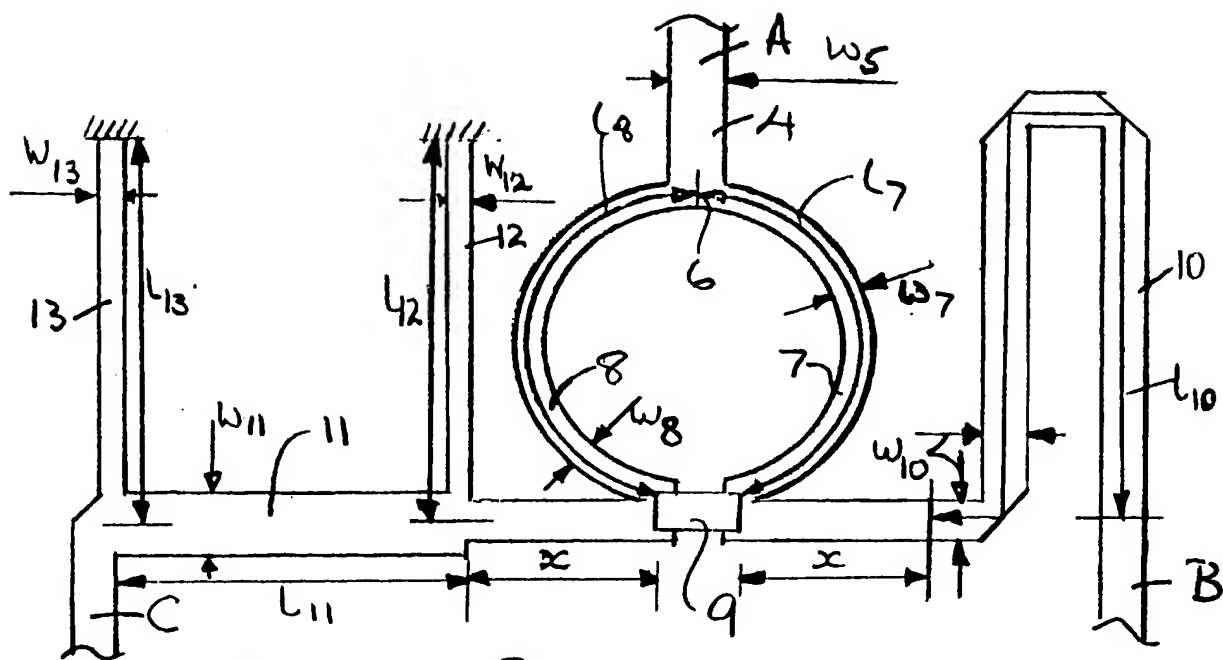

Figure 2

FIGURE 1
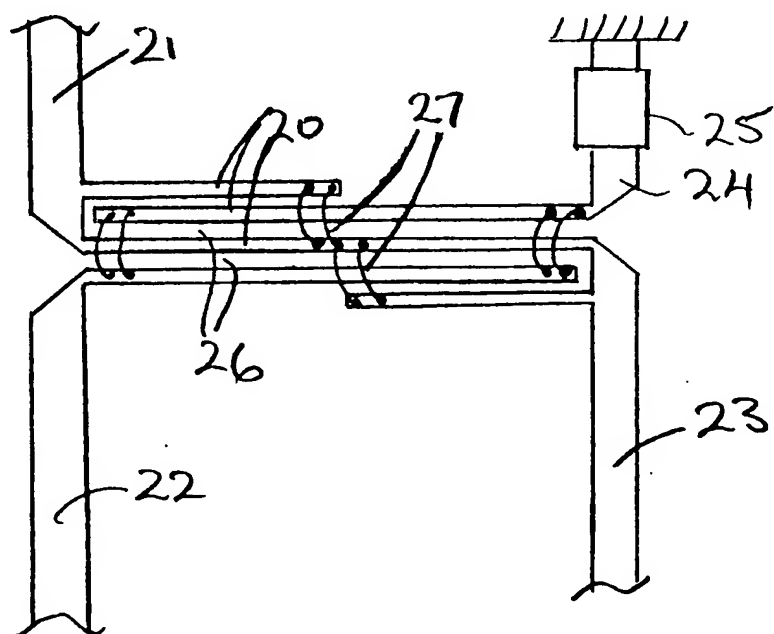

FIGURE 2

FIGURE 3

FIGURE 4

SPECIFICATION
Microwave power divider

The present invention relates to a microwave
5 power divider.
It is convenient to be able to divided a microwave
signal into two components of equal power but
having a 90° phase difference between them or
indeed to recombine them again. A device for
10 achieving this is variously known as a " 3dB 90°
Hybrid" or "3dB Quadrature Coupler". In this
specification such a device is referred to as a "3dB
Quadrature Power Divider". A typical use of such a
device is in splitting a microwave signal into
15 components which can then be individually
amplified and re-combined in a similar divider to
produce the original signal in amplified form.
A known wide-band power divider is the Lange
coupler. I believe this to be the only wide-band
20 power divider suitable for microwave integrated
circuit applications. The Lange coupler comprises
interspaced conductor strip fingers. It performs
adequately at the lower microwave frequencies.
Above 8 GHz the fingers become very small and are
25 difficult to produce. In the "J" band, 10—20 GHz, the
application of the Lange couple is restricted to the
thin-film integrated circuits — an expensive
technology. Further selected ones of the fingers
must be interconnected. This is an expensive task
30 and degrades the performance at high frequencies.
The object of the invention is to provide an
improved microwave power divider.
According to the invention, there is provided a
microwave power divider comprising:—
35 a Wilkinson power splitter, at the two outputs of
which signals of substantially equal phase are
present for a signal at the input of the splitter having
a total power which is substantially equal split into
the two output signals;
40 a quadrature delay connected to one output of the
power splitter; and
an incremental phase compensator, in the form of
a bandpass filter, connected to the other output of
the power splitter, whereby the output signals of the
45 quadrature delay and the compensator are in
quadrature;
the frequency characteristics of the compensator
being such that any incremental phase change in
the quadrature delay due to an increment in
50 frequency from a centre frequency is substantially
matched by a corresponding incremental phase
change in the compensator such that the said output
signal of the delay and the compensator remain
substantially in quadrature throughout a pre-
55 determined broad-band frequency range.
It should be noted that the actual phase delay in
the quadrature delay between the output of the
power splitter and the output of the delay will
exceed 90° by the amount corresponding to the
60 inherent phase delay of the compensator, i.e. its
phase delay at the centre frequency when the
compensator produces no incremental phase
change.
In the preferred embodiment the compensating
65 bandpass filter is a direct coupled stub filter, with a

characteristic impedance of Z_o. Preferably a two
stub filter is employed, although one or three or
possibly more may be employed.
The quadrature delay can be a transmission line
70 of suitable length with a characteristic impedance of
Z_o.
Either a compensated or a uncompensated
Wilkinson splitter can be employed, having a
characteristic impedance of Z_o.
75 The power divider of the invention is preferably
manufactured in "micro-strip" form, that is in the
form of conductive metallic strips of pre-determined
width on an insulating substrate.
Micro-strip manufacture is mainly carried out at
80 two different levels, namely "soft board" or "soft
substrate" on the one hand and "thin film" on the
other hand. Soft board circuits comprise etched
copper tracks on a plastics material board. This is a
relatively cheap technology. Thin film circuits
85 comprise gold tracks on ceramic substrate. This is a
relatively expensive technology.
As intimated above, the Lange coupler is
restricted to a maximum practical frequency of
around 8 MHz in "soft board" circuits, so that "thin
90 film" circuits are required at higher frequencies in
the "J" band. An advantage of the present invention
is that it enables a "J" band wide-band 3dB
quadrature power divider to be manufactured in
"soft board" form. Further, it is anticipated that
95 wide-band 3dB quadrature power dividers will be
able to be manufactured at frequencues above the J
band at which Lange couplers cannot practically be
manufactured, again because of finger width and
difficulty in connecting the necessary inter-finger
100 wires.
To help understanding of the invention, a specific
embodiment thereof will now be described by way
of example and with reference to the accompanying
drawings, in which:—
105 Figure 1 is a block diagram of a power divider in
accordance with the invention; and
Figure 2 is a diagrammatic plan view of the power
divider of Figure 1.
Referring first to Figure 1, the power divider
110 comprises a Wilkinson splitter 1 having a
characteristic impedance Z_o at its input A, and
outputs B_1, C_1. At the splitter's output B_1, it is
connected to a transmission line 2, and having the
same characteristic impedance Z_o forming a
115 quadrature delay. At the splitter's output C_1 is
connected to a bandpass filter 3, forming a
compensator and having the same characteristic
impedance Z_o.
At the power divider's design or centre frequency,
120 the filter 3 will delay a signal passing from C_1 to C by
a certain phase. The transmission line 2 has a length
such that a signal passing from B_1 to B is delayed by
this certain phase plus 90°. Thus a centre frequency
signal entering at A is split into two equal halves
125 having the same phase at B_1 to C_1. Then by the time
these halved signals reach the outputs of the divider
at B and C, they will be 90° out of phase, i.e. in
quadrature.
As the frequency of the input signal varies from
130 the centre frequency, to two halves will remain in

phase at B_1 and C_1. However the phase delay in the
line 2 will vary linearly with the frequency. As the
frequency increases by an amount Δf, the phase
delay will also increase by an increment $\Delta\psi$. If the
5 filter 3 were a transmission line of length equivalent
to 90° less than that of the line 2, the equivalent
increment in phase would be less than $\Delta\psi$ leading to
the signals being out of quadrature at B and C. To
compensate for this, the group delay characteristics
10 of the filter 3 are chosen such that substantially the
same phase increment $\Delta\psi$ occurs in itself as occurs
in the line 2 for the frequency increment Δf. $\Delta\psi$ in
the line 2 is linear with Δf. Accordingly, although the
invention is not intended to be so restricted, the
15 characteristics of the filter 3 are chosen to give an
approximately linear compensation.

Turning now to Figure 2, a view of the power
divider in 50 ohm micro-strip form is shown. A 50
ohm line 4 from the input A divides at 4 into two 70.7
20 ohm lines 7 and 8, each ¼ wave long. The nodes B_1
and C_1, at the ends of these lines, are interconnected
by a 100 ohm resistor 9, to form an uncompensated
Wilkinson power splitter. The quadrature delay is
provided by a ½ wave long 50 ohm transmission line
25 10, connecting node B_1 to node B, that is one output
of the network. Node C_1 is connected to node C via a
¼ wave long 42 ohm line 11. The other output of the
network is node C. Two short-circuited to ground 60
ohm ¼ wave long stubs 12 and 13 are connected to
30 node C_1 and C, to form, together with line 11, a
bandpass filter.

At the centre frequency, line 10 delays the signal
by 180°C, line 11 delays the signal by 90° and stubs
12 and 13 have no effect, leading to 90° and stubs 12
35 and 13 have no effect, leading to 90° phase
difference at the outputs B, C. The bandpass filter,
having the 42 ohm line and the 60 ohm stubs,
displays a 2 pole chebyshev 0.1 dB rippled type of
response. Referring to filter tables, such a filter has
40 approximately 1.6 second pass band normalized
group delay. As a 90° delay expressed as normalized
group delay is 1.57 sec., it is apparent that the phase
change in the delay line is compensated in the pass-
band of the bandpass filter, thus the output phase
45 differential of 90° is maintained.

The power divider of Figure 2 has the following
characteristics:

Characteristic impedance:	50 ohm
Relative Frequency Range:	0.66—1.34
Amplitude Flatness:	± 0.05dB
Phase between B & C:	90° ± 5
Return loss at port C:	better than 16 dB

It should be noted, that by varying the parameters of
60 lines 11, 12 and 13, different performance
characteristics can be obtained. For instance with
higher line impedances a Butterworth type of filter
response can be achieved. This will improve the
return loss and the amplitude/phase ripple at the
65 expense of a reduction in band width.

Turning now to Figures 3 and 4, the preferred
physical track layout of a power divider of th
invention can be seen in Figure 3 and an equivalent
layout for a Lange coupler can be seen in Figure 4.
70 In Figure 3, the reference numerals and letters
have the same signifance as for Figure 2. For:—

Frequency Range of	7 to 14 Ghz, and
75 A Substrate Dielectric constant (e_r) of	10.2,

the tracks have the following lengths:—
80

l_7	2.8	mm
85 l_8	2.8	mm
l_{10}	5.4	mm
l_{11}	2.7	mm
90 l_{12}	2.75	mm
l_{13}	2.75	mm

95 The x dimensions are of equal length.
The width of the tracks is dependent upon the
dielectric, i.e. board, thickness to an earth backing
plate. For a typical substrate thickness of 0.635 mm,
which is suitable for a soft substrate or a thin film
100 circuit, the tracks have the following widths:—

w_5	0.61 mm
105 w_7	0.25 mm
w_8	0.25 mm
w_{10}	0.61 mm
110 w_{11}	0.80 mm
w_{12}	0.40 mm
115 w_{13}	0.40 mm

These widths are achievable with conventional soft
board techniques.
120 By contrast, the Lange coupler of Figure 4 has
small width fingers 20 to which wires 27 must be
connected. For the same frequency range, dielectric
constant and thickness, the Lange coupler has an
input track 21 and two output tracks 22, 23 all of
125 equal width of 0.61 mm as 50 ohm lines. One of the
terminals 24 of the Lange coupler is connected to
earth via a 50 ohm resistor 25.
These lines have their interdigitated fingers 20
spac d by gaps 26. These have the following
130 widths:—

| Fingers 20 | 0.06 mm |
| Gaps 26 | 0.05 mm |

5 This it can be seen that in comparison with the power divider of the invention, the Lange fingers are approximately a quarter of the width of the narrowest lines of the invention. The gaps 26 also are equally narrow. Besides the difficulty in forming
10 these fingers 20 the wires 27 must be attached to them.

When higher frequency power dividers are to be made, thinner dielectrics are advisable. Track widths are reduced linearly with dielectric thickness. Thus it
15 will be appreciated that when the limit with increasing frequency of the feasibility of manufacturing Lange couplers in any technique is reached, the narrowest tracks of an equivalent power divider of the invention are still four times as
20 wide and no wire bonding is required. Accordingly power dividers of the invention can be constructed to operate at higher frequencies.

CLAIMS
25   1. A microwave power divider comprising:—
a Wilkinson power splitter, at the two outputs of which signals of substantially equal phase are present for a signal at the input of the splitter having a total power which is substantially equally split into
30 the two output signals;
a quadrature delay connected to one output of the power splitter; and
an incremental phase compensator in the form of a band pass filter connected to the other output of
35 the power splitter, whereby the output signals of the quadrature delay and of the compensator are in quadrature.

2. A divider according to claim 1, in which the frequency characteristics of the compensator are
40 such that any incremental phase change in the quadrature delay due to an increment in frequency from a centre frequency is substantially matched by

a corresponding incremental phase change in the compensator, so that the output signals of the
45 quadrature delay and of the compensator remain substantially in quadrature over a pre-determined broad-band frequency range.

3. A divider according to claim 1 or 2, in which the actual phase delay in the quadrature delay between
50 the one power splitter output and the delay output exceeds 90° by the amount corresponding to the inherent phase delay of the compensator at a centre frequency when the compensator produces no incremental phase change.

55   4. A divider according to claim 1, 2 or 3, in which the compensating band pass filter is a direct coupled stub filter, with a characteristic impedance of Z_o.

5. A divider according to claim 4, in which the filter
60 is a two stub filter.

6. A divider according to any preceding claim, in which the quadrature delay is a transmission line of selected length with a characteristic impedance of Z_o.

65   7. A divider according to any preceding claim, in which the Wilkinson splitter is compensated, having a characteristic impedance of Z_o.

8. A divider according to any of claims 1 to 6, in which the Wilkinson splitter is uncompensated,
70 having a characteristic impedance of Z_o.

9. A divider according to any preceding claim, manufactured in the form of conductive metallic strips of predetermined width on an insulating substrate.

75   10. A divider according to claim 9, in which the components comprise etched copper tracks on a plastics material board.

11. A microwave power divider substantially as hereinbefore particularly described with reference
80 to Figures 1 and 2 of the accompanying drawings.

12. A microwave power divider substantially as hereinbefore particularly described with reference to Figures 1 to 3 of the accompanying drawings.